Sue Oct 15, 1992

Hazard Potential and Paleoseismic Implications of Liquefaction-Induced Landslides Along the Wasatch Front, Utah

Agreement No. 14-08-0001-G2058

Kimm M. Harty, Mike Lowe, and Gary E. Christenson
Utah Geological Survey
2363 S. Foothill Dr.
Salt Lake City, Utah 84109

(801) 467-7970

BACKGROUND AND SUMMARY OF OBJECTIVES

Thirteen late-Pleistocene/Holocene liquefaction-induced landslides have been identified along the Wasatch Front by previous researchers. The goal of this study is to further constrain the timing of these landslides, to determine if they have experienced recurrent movement, and to evaluate their hazard potential. If recurrent movement can be shown, local governments are more likely to consider this in development on these features, or look for an area-wide mitigation strategy to reduce the risk. A further objective, identified during the course of the study, is to determine whether some of these 13 features may, in fact, be related to other processes such as differential subsidence or other effects of a fluctuating shallow water table and artesian conditions. Techniques used to investigate the features include air-photo interpretation, geologic and geomorphic mapping, and trench excavations. All radiocarbon dates are from standard radiocarbon dating of bulk soil samples. The dates were calendar calibrated (Stuiver and Reimer, 1986) and rounded to the nearest decade. Where appropriate, we subtracted 300 years from radiocarbon ages prior to calendar calibration to account for the mean residence time of carbon in the buried soil.

INVESTIGATIONS UNDERTAKEN

Geomorphic mapping at 1:10,000 or 1:20,000 scales and reconnaissance field checking was completed for all the landslides. Both internal geomorphic features such as shear scarps, ridges, hummocks, and depressions, and external regional features such as river terraces, deltas, and major and minor shorelines of Lake Bonneville were mapped.

Eleven excavations were completed on the following five landslides: "North Ogden" (Weber County); "North Salt Lake" and "Farmington Siding" (Davis County); and "Springville/Spanish Fork" and "Beer Creek" (Utah County). The trenches were logged and bulk soil samples were taken for radiocarbon dating. Only three trenches (one on the North Ogden landslide and two on the Farmington Siding landslide) contained evidence for liquefaction and material suitable for radiocarbon dating. Cities and counties in the landslide areas cooperated in the investigations by providing backhoes for the trench excavations.

RESULTS OBTAINED

Box Elder County Landslides

Six areas of lateral-spread or flow landslides were mapped in Box Elder County (Oviatt, 1986a,b; Personius, 1988). Most of these landslides were inferred to have occurred approximately 12,000-13,000 years ago, based on undeformed lacustrine shorelines that cut the surfaces of the slope failures at approximately 1,347-1,353 m elevation (Oviatt, 1986a,b; Personius, 1988). Geomorphic mapping suggests that most of these landslides are rotational slumps or complex landslides, rather than liquefaction-induced lateral spreads or flow slides. Most of the main scarps of the landslides are on steep slopes, and some of the failures have multiple back-tilted minor scarps characteristic of slumps. Most of the failures formed in Lake Bonneville gravels, and many of the deposits consist of isolated knolls of gravel that lie on undisturbed finer lake sediments, suggesting that the slope failures flowed or spread out into the lake.

Because most of these landslides are cut by a single Lake Bonneville shoreline, they were likely synchronous events, perhaps triggered by an earthquake as proposed by Oviatt (1986a,b). However, it may be that these landslides are simply earthquake-induced landslides rather than liquefaction-induced landslides. No evidence of liquefaction was observed in exposures of the landslide deposits, but this does not preclude its existence. Tilted bedding was observed in some stratified sand and gravel deposits, but this can be explained by slumping of landslide blocks. Because the landslides occur on steep slopes, liquefaction is not necessary to account for the failures.

North Ogden Landslide

The approximately 30 km^2 North Ogden lateral spread was first identified by Miller (1980), and subsequently mapped in parts by Personius (1988) and Nelson and Personius (1990), but little information was available regarding the age of this landslide. We excavated two trenches into the North Ogden landslide. Stratigraphic relationships in a trench placed across the main scarp suggest that the landslide likely failed as a flow slide rather than as a lateral spread. A second trench excavated into a hummock on the main body of the landslide showed evidence of liquefaction and a means to constrain the timing of at least one liquefaction event. In this trench, we found numerous sand-filled fractures in fine-grained mud-flow, or possibly flow-slide deposits that post-date the Lake Bonneville cycle. We believe the sand was injected into fractures due to liquefaction during an earthquake. Radiocarbon dates on of the buried soils constrains the date of occurrence of the liquefaction event as sometime after 7,860 [± 250] cal. yr B.P.

Severely deformed and contorted bedding was also observed in the trench that may be related to as many as two liquefaction-induced flow slides. The first of these flows occurred prior to 7,860 [± 250] cal. yr B.P. The second flow, which contained isolated blocks of stratified Lake Bonneville sediments, occurred after 7,860 [± 250] cal. yr B.P. but sometime prior to 3,390 [± 230] cal. yr B.P.

East Ogden landslide

Faults, tilted beds, and sand dikes exposed in trenches on the East Ogden landslide at Weber State University were first described by Pashley and Wiggins (1972). They attributed the features to a large translational landslide similar to the Turnagain Heights landslide that occurred during the 1964 Anchorage, Alaska, earthquake. Woodward-Clyde Consultants (1985) examined faults exposed in a building excavation on a scarp at the Weber State University campus and determined that the faults may represent seismically-induced slumping or lateral spreading, or gravity-induced subaqueous landsliding that may have occurred when the level of Lake Bonneville was high and the deposits were saturated. This event occurred prior to the deposition of Provo-age nearshore sands about 11,000-13,000 years ago, as the sands were exposed in the foundation excavation and were not faulted (Woodward-Clyde Consultants, 1985). Nelson and Personius (1990) mapped this scarp as the main scarp of the East Ogden landslide, but concluded that parts of the landslide postdate the Provo shoreline whereas other parts probably predate the Bonneville shoreline. The East Ogden landslide is heavily urbanized, and we were unable to identify a trench site that would help determine the age(s) of the landslide.

West Kaysville Landslide

This feature is west of the city of Kaysville, and was first mapped as a lateral-spread landslide by Miller (1980). Anderson and others (1982) also mapped the landslide as a failure by lateral spreading, and recognized a poorly developed Gilbert shoreline cut across its surface. The landslide is buried on the northwest and southeast margins by alluvial-fan sediments, and has a main scarp that is difficult to distinguish in the field, but that is visible on 1:10,000-scale aerial photographs. The presence of the Gilbert shoreline across the surface of the feature indicates it formed prior to about 10,000 years ago.

Farmington Siding Landslide Complex

The Farmington Siding landslide complex was first mapped by Van Horn (1975), who described longitudinal ridges and undrained depressions on the surface of the landslide complex; and faults, folded beds, and injected sand in exposures of the interior. The landslide complex was mapped as three separate slope failures by

Nelson and Personius (1990), and as one or two separate landslides by other workers (Van Horn, 1975; Miller, 1980; Anderson and others, 1982; Chen and Associates, 1986). The Gilbert shoreline is mapped by Anderson and others (1982) as crossing the southern part of the landside complex, but not the northern part. Thus, the southern two landslides, as mapped by Nelson and Personius (1990), probably occurred more than 10,000 years ago. Organic clay immediately overlying landslide deposits in Farmington Bay, which correspond to the younger, northern Farmington Siding landslide, gave a radiocarbon age estimate of 2,930 [± 70] yr B.P. (Everitt, 1991). This date is similar to dates from the penultimate surface-faulting earthquake on the Weber segment of the Wasatch fault zone (Nelson, 1988; Forman and others, 1991; McCalpin and others, in preparation).

To resolve the age of landsliding, we excavated one trench on one of the older landslides, and two trenches on the younger landslide. Bedded lacustrine sediments exposed in the trench across a hummock on the older landslide were slightly back-tilted, presumably due to landsliding, but no material suitable for age dating was obtained from the trench. We excavated two trenches across a wedge-shaped mound near the main scarp of the younger landslide. In one of the trenches, a block of soil incorporated into the landslide deposit gave a radiocarbon age estimate of 4,630 [± 340] cal. yr B.P., indicating that the landslide formed sometime after this date. In the second trench, a radiocarbon age estimate from a buried soil that formed on the landslide indicates that it occurred sometime prior to 2,650 [± 225] cal. yr B.P. These dates bracket the age estimate obtained by Everitt (1991).

North Salt Lake Landslide

This landslide is mapped as two separate lateral spreads by Van Horn (1982) and Anderson and others (1982). Anderson and others (1982) excavated two shallow test pits on the northern, younger landslide, and one test pit on the older landslide. The test pit on the older landslide showed no evidence of liquefaction or disturbed bedding. The test pits on the younger landslide showed minor bedding disturbance in the form of 1-2 cm offsets in marker beds (Anderson and others, 1982). We excavated two narrow trenches down the slope of a 2.5-meter-deep land drain that crosses both landslides. No evidence of liquefaction or sediment deformation was observed in either of the two trenches, each of which was on a separate landslide. Based on our investigation, the features, which may or may not be lateral-spread landslides, are both older than the Gilbert shoreline (approximately 10,000 years ago).

Springville/Spanish Fork Landslide

Situated between the cities of Springville and Spanish Fork, this feature was mapped by Miller (1982) and Machette (1989). It is mapped as a possible lateral-spread landslide by Miller (1982), and its age is estimated as Holocene to upper Pleistocene

(Machette, 1989). We excavated three trenches on this feature; one in the center of the deposit, another near the distal "toe" of the feature, and one across a previously unmapped lineament on the feature. The lineament is likely a Lake Bonneville shoreline that trends NE-SW, and can be traced for about 2.3 km. None of the trenches showed evidence of liquefaction, and only the trench excavated across the toe of the feature showed evidence of deformed bedding. In this trench, we observed minor offsets (< 1 cm) in a thin clay marker bed, suggesting brittle deformation.

Although dissected and eroded in places, the shoreline was not displaced by the landslide, and thus appears to post-date formation of the feature. However, surface topography on the feature, particularly depressions near the "toe", appear younger than a cross-cutting shoreline would suggest. We offer three explanations that may explain the apparent discrepancy: (1) post-Bonneville liquefaction-induced landsliding did not occur within all the areas mapped as a lateral spread by Miller (1982) and Machette (1989); (2) the feature is not a lateral spread, but liquefaction during earthquake ground shaking created surface depressions, giving the appearance of a lateral spread; or 3) the feature is not a lateral spread, but an area affected by differential subsidence or other conditions caused by a fluctuating shallow water table, spring discharge, and artesian ground-water flow. Evidence obtained thus far favors the latter explanation as the most plausible, but further study is needed to resolve the question.

Beer Creek Landslide

The Beer Creek landslide is north of the city of Salem, and was first mapped as a queried lateral-spread landslide by Miller (1982). He described ridges parallel to the possible landslide main scarps and subdued mounds, hummocks, and undrained depressions on the surface of the landslide. Machette (1989) remapped the feature, removing the queries, and noted that the horizontal bedding of the original lacustrine sediment commonly had been contorted or destroyed by the movement. We excavated a trench across the main scarp of the possible landslide, but did not find any material suitable for age dating, or information to confirm that the feature is a landslide.

CONCLUSIONS

Geomorphic mapping and trench excavations produced positive, negative, and in some cases inconclusive evidence for liquefaction and liquefaction-induced landsliding along the Wasatch Front. The hazard potential of the features evaluated in this study is variable because of the differences in failure mechanisms and uncertainty in origin of a number of the features. However, recurrent landsliding has likely occurred at least within the boundaries of the North Ogden and Farmington Siding landslides within Holocene time, and future recurrent movement on these and some of the other features can be expected and needs to be considered by local governments during land-use evaluations.

REFERENCES CITED

Anderson, L.R., Keaton, J.R., and Ellis, S.J., 1982, Liquefaction potential map for Davis County, Utah: Utah State University Department of Civil and Environmental Engineering, and Dames and Moore Consulting Engineers unpublished report for the U.S. Geological Survey, 50 p.

Chen and Associates, 1986, Preliminary geotechnical investigation, Davis County Correctional Facility Site B, Farmington, Utah: Unpublished consultant's report for the Davis County Sheriff's Department, Salt Lake City, Utah, 11 p.

Everitt, Ben, 1991, Stratigraphy of eastern Farmington Bay: Utah Geological and Mineral Survey, Survey Notes, v. 24, no. 3, p. 27-29.

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp-derived colluvium--deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

Machette, M.N., 1989, Preliminary surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2109, scale 1:50,000.

McCalpin, James, Forman, S.L., and Lowe, Mike, in preparation, Reinterpretation of Holocene faulting at the Kaysville trench site, Weber segment of the Wasatch fault zone: Manuscript in preparation.

Miller, R.D., 1980, Surficial geologic map along part of the Wasatch Front, Great Salt Lake Valley, Utah: U. S. Geological Survey Miscellaneous Field Investigations Map MF-1198, scale 1:100,000.

----1982, Surficial geologic map along the southern part of the Wasatch Front, Great Salt Lake and Utah Valleys, Utah: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1477, scale 1:100,000.

Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, in Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province: Geological Society of America Meeting Field Trip Guidebook, Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 26-32.

Nelson, A.R., and Personius, S.F., 1990, Preliminary surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2132, scale 1:50,000.

Oviatt, C.G., 1986a, Geologic map of the Honeyville quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 88, scale 1:24,000.

----1986b, Geologic map of the Cutler Dam quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 91, scale 1:24,000.

Pashley, E.F., Jr., and Wiggins, R.A., 1972, Landslides of the northern Wasatch Front, in Hilpert, L.S., editor, Environmental geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. K1-K16.

Personius, S.F., 1988, Preliminary surficial geologic map of the Brigham City segment and adjacent parts of the Weber and Collingston segments, Wasatch fault zone, Box Elder and Weber Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2042, scale 1:50,000.

Stuiver, Minze, and Reimer, P.J., 1986, CALIB & DISPLAY software: Radiocarbon, v. 28, p. 1022-1030.

Van Horn, Richard, 1975, Largest known landslide of its type in the United States--a failure by lateral spreading in Davis County, Utah: Utah Geology, v. 2, no. 1, p. 83-87.

----1982, Surficial geologic map of the Salt Lake City North quadrangle, Davis and Salt Lake Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1404, scale 1:24,000.

Woodward-Clyde Consultants, 1985, Evaluation of fault activity and potential for future tectonic surface faulting--Allied Health Science Building site, Weber State College, Ogden, Utah: Unpublished consultant's report, 10 p.